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WATER RESOURCES ACTIVITIES IN THE UNITED STATES. EVAPORATION REDUCTION AND SEEPAGE CONTROL

Select Committee on National Water Resources
U. S. Senate

December 1959

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86th Congress
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COMMITTEE PRINT NO. 23

WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

EVAPORATION REDUCTION AND SEEPAGE CONTROL

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS
FIRST SESSION

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UNITED STATES
GOVERNMENT PRINTING OFFICE
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(Pursuant to S. Res. 48, 86th Cong.)

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STATEMENT BY THE CHAIRMAN

DECEMBER 29, 1959.

To the Members of the Select Committee on National Water Resources:

In any irrigation project only a portion of the total available water supply is put to beneficial use in growing crops. Evaporation into the atmosphere and seepage into the ground from reservoirs, canals, and diversion ditches, each diminish the amount of water which would otherwise be available for crop production. All of this water is not lost, as the seepage may augment usable ground water supplies, or eventually reappear as surface runoff for use downstream. However, the presence of moisture in and along the project works induces growth of water-loving, generally worthless, vegetation which in turn depletes available supplies through evapotranspiration. In addition, losses are incurred because operational procedures are not sufficiently exact to permit the transfer of the exact water requirement from the source of supply to the point of use. In view of all these losses, actual consumptive use on a project may be but one-half or less of the available supply.

As the committee is directed by the provisions of Senate Resolution 48 to study evaporation reduction and seepage control, among other means of increasing the usefulness of our available water resources, and as the most immediate practical use of the techniques will be to increase the available water supplies for irrigation and water supply projects in the West, I asked the Secretary of the Interior to have a report prepared by the Bureau of Reclamation on this subject. The Bureau was asked to take cognizance of the work done in this field by other agencies, and to report to the committee on measures for minimizing water storage and transportation losses, giving information on the problems involved and recommendations for future research and development in this field. To the extent practicable, benefit-cost relationships and estimates of amounts of water conservation likely to be achieved through 1980 were also requested.

The Bureau of Reclamation's report concludes that by 1980 improvements in irrigation water conveyance works could result in reduction of seepage losses by about 1½ million acre-feet, surface treatment of reservoirs could save about 2 million acre-feet of water, and eradication of nonbeneficial plant growth could reduce consumptive water by another million acre-feet. The report points out some of the problems, such as the need in some places for changes in water-right law to clarify ownership of water saved, and the present high costs of some of the measures, which in some areas exceed the costs of developing new water supplies. The Bureau believes that by 1980 the costs of water saved by surface treatment of reservoirs could be reduced to about one-fourth of the present-day cost of $40 per acre-foot. Recommendations are made of fields in which continued and future study and research might profitably be conducted.

The report will be of interest to the Members of the committee, to other Members of the Senate, and to all who are interested in improving the use of our available water resources. Accordingly, I am having it printed as one of our committee prints on water resources activities in the United States.

ROB'T S. KERR,
Chairman, Select Committee on
National Water Resources.

COMMUNICATIONS

JULY 14, 1959.

Hon. FRED A. SEATON,
Secretary of the Interior, Department of the Interior,
Washington, D.C.

MY DEAR MR. SECRETARY: Thank you for Assistant Secretary Aandahl's letter of July 9, 1959, enclosing a copy of the report entitled "Water-Loss Investigations: Lake Hefner 1958 Evaporation Reduction Investigations." The committee is deeply interested in the information contained in the report, which relates to the control of evaporation from Lake Hefner by a film of hexadecanol, and notes the conclusion that much additional research needs to be done before the development reaches the stage where specific recommendations can be made for selected types of reservoir, based on firm cost-benefit data.

Under the provisions of Senate Resolution 48, referred to in my letter of June 15, the attention of this committee is directed to new technical methods and improved processes for increasing the usefulness of available water resources, including, among others, evaporation reduction and seepage control. While the information contained in the Lake Hefner report is very helpful with regard to evaporation reduction, the committee is in need of a briefer, more comprehensive survey of both fields, covering work done by all Federal and non-Federal agencies, to serve as background for its work in these fields. We believe that the Bureau of Reclamation is well qualified to prepare such a report. Accordingly, it is requested that a report on measures for minimizing water storage and transportation losses be prepared for us by the Bureau of Reclamation.

Principal objective of the report should be to furnish background for use in considering steps that might be taken to encourage developments in these fields. The report should contain a brief description of the problems of water loss through reservoir storage and transportation in the 17 Western States. Chemical and mechanical means of avoiding such losses should be discussed, giving attention to the feasibility of applying such measures with respect to such aspects as toxicity, disturbance of water rights, and other problems which may arise. Benefit-cost relations should be given for such measures to the maximum extent practicable, and estimates of amounts of water conservation likely to be achieved by 1980 through the measures described should be given by major river basin. Cognizance should be taken of work done by other Federal and non-Federal agencies in these fields.

The report should conclude with recommendations for future research and development in this field with comments as to the role which the Federal Government should take in such research and development.

We would like this subject to be covered in a summary report of not more than 10,000 words with whatever charts, tables, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this information could be furnished the committee by October 15, 1959.

The committee staff will be glad to discuss any problems which may arise in the preparation of the report with representatives of the Department of the Interior.

Sincerely yours,

ROB'T S. KERR,
Chairman, Select Committee on
National Water Resources.

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U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., December 24, 1959.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: Pursuant to your request of July 14, 1959, the Bureau of Reclamation has prepared a report on "Measures for Minimizing Water Storage and Conveyance Losses in the 17 Western States."

The report contains a brief description of the problems of water loss through reservoir storage and transmission, as well as possible measures for alleviating these losses. Economic consideration of remedial measures is discussed, and recommendations are made regarding future research and development in this field with comments as to the role which the Federal Government should take in such research and development.

Twenty copies of the report are being transmitted under separate cover. The original artwork for the illustrations is in our files and can be made available to you should you so desire.

Sincerely yours,

FRED A. SEATON,
Secretary of the Interior.

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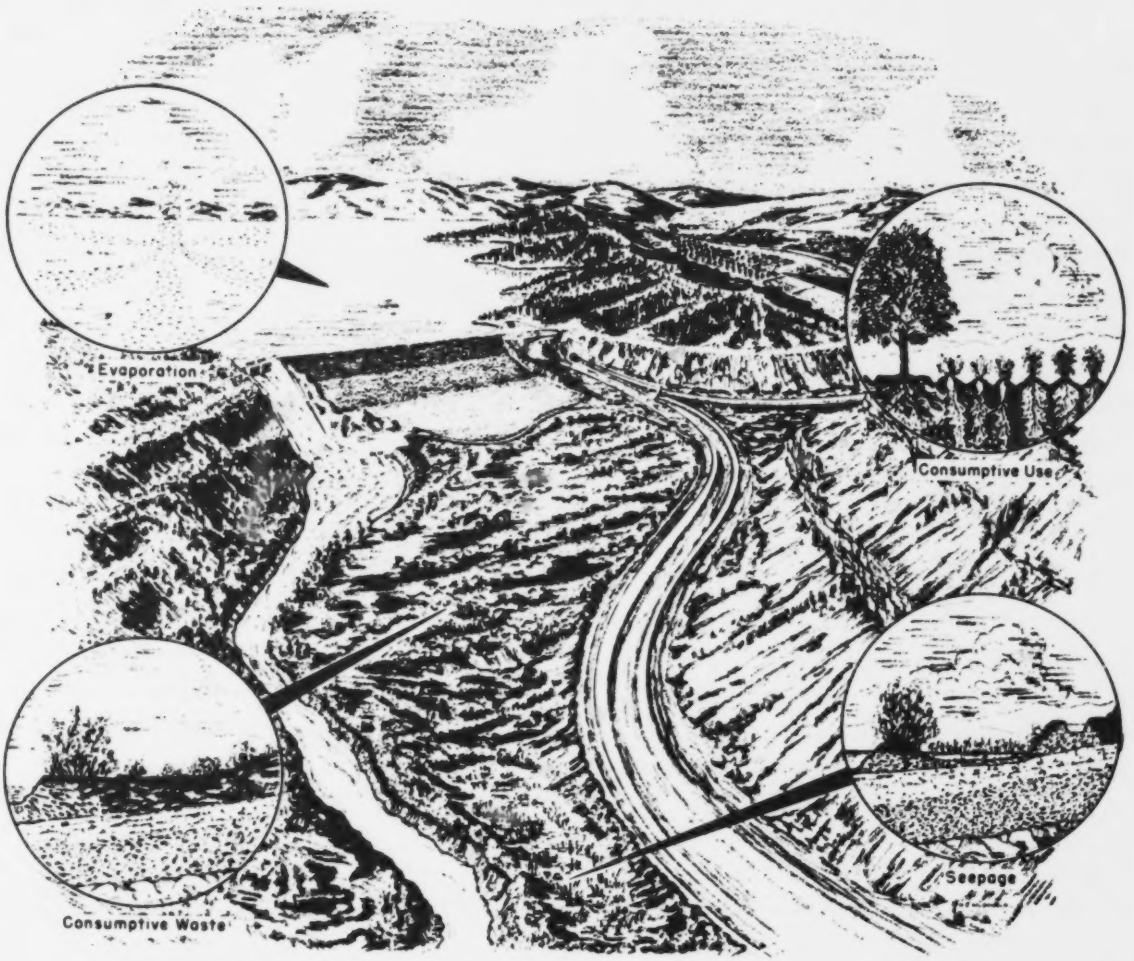

Where the water goes.

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EVAPORATION REDUCTION AND SEEPAGE CONTROL

Introduction

A portion of the water stored and diverted is lost before it reaches its intended point of use—the farmer's fields in irrigation and the supply taps in industrial and municipal use.

This report evaluates and summarizes present knowledge of current and potential techniques for reducing water losses from irrigation projects in the 17 Western States. Where possible the evaluation is on a regional basis in harmony with the aims of the overall report of the Senate select committee. The report provides background for decisions on future research and technical study that will assist in solving the problems of expanding water demand.

The report presents conclusions reached from these analyses and makes recommendations for further research and study to reduce evaporation and seepage. It describes the role of the Federal Government in a research program. Factors relating to water storage and transportation efficiency are examined. Also presented are methods for increasing water storage and transportation efficiency, a study of the problems arising from existing State water laws, and economic analyses of the value of water under present conditions.

The paucity of quantitative information on water distribution and waste is recognized at the outset as a principal problem in preparing this report.

To assure a clear understanding of the concept presented in this report, a glossary of the more complex terms is included.

Glossary

Water storage efficiency

Water storage efficiency is the ratio of the quantity of water delivered from a storage facility to the quantity of water delivered to the facility.

Water conveyance system efficiency

The efficiency of a water conveyance system is the ratio of quantity of water delivered to the users by the system to the quantity delivered to the system headworks.

Evapotranspiration

Evapotranspiration is the sum of the volumes of water used by the vegetative growth in transpiration and building of plant tissues, and evaporation from the plants and adjacent soil.

Evaporation

Evaporation is the quantity of water which escapes from a water surface as vapor. It does not include evaporation from surfaces included in evapotranspiration.

Consumptive use

Consumptive use is the total evapotranspiration of the water returned to the atmosphere and retained in plant tissue by vegetation which is essential to man's existence, of high economic value, or contributes to man's comfort.

Consumptive waste

Consumptive waste is the total evapotranspiration from vegetation which is of low economic value or contributes little or nothing to the comfort of man.

Operational waste

Operational waste is water intentionally turned out of a canal system to facilitate administrative operation. Such water is not usually available to water users.

Return flow

Return flow is that portion of the diverted water which eventually finds its way back to a natural channel.

Conclusions

1. Variability of climate, soils, topography, and location affect seepage and evaporation to such an extent that general statements may be ambiguous and misleading.

2. Seepage losses customarily reported are not basin losses and require defining to be of general use. If true basin loss is to be accurately eval-

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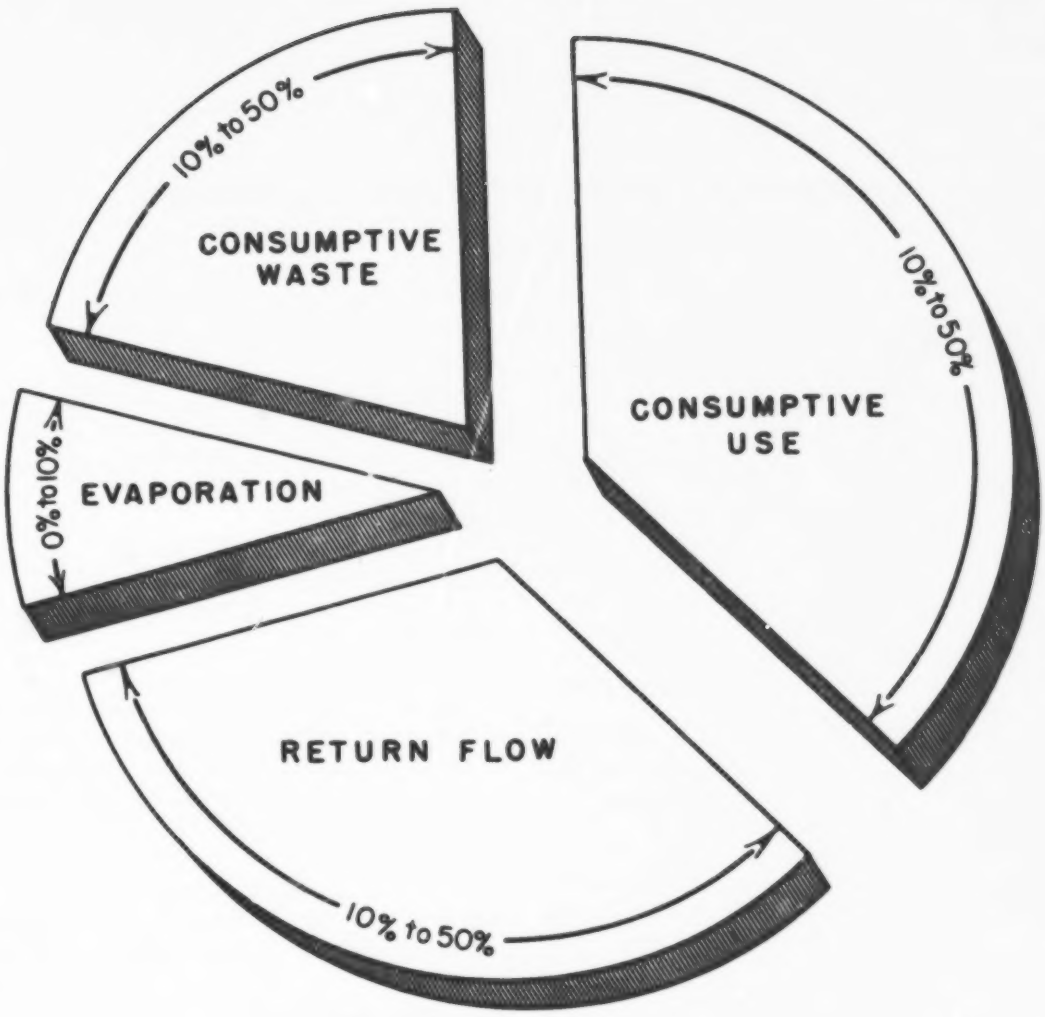

FIGURE 1.—Variations in distribution of water on typical irrigation projects.

uated, considerable study and measurements will be required.

3. Evaporation and evapotranspiration may be considered as the only major basin losses if flow out of the basin is considered separately.

4. In basins with critically limited water supplies, conservation, reallocation or importation of water are practical solutions. Conservation is usually less costly than importation and less objectionable than reallocation.

5. Water users are accustomed to water charges which are substantially less than the potential economic value of water. The price paid for water may be expected to rise as economic competition for available water increases and as more expensive competitive sources of supply are developed.

6. Decisions concerning the location of water use, of course, cannot be made entirely on the basis of prices. The present price of storage water ranges from $1 to $35 per acre-foot for irrigation and from $5 to in excess of $75 per acre-foot for municipal use, and may be expected to increase substantially as growth and general economic de-

velopment proceed between now and the year 1980. By that time these prices may perhaps double.

7. Present water measurements serve the purpose for which intended but generally do not supply precise answers to questions of water distribution throughout an entire river basin, or even an entire project.

8. Seepage can be reduced by canal linings, by treatment of the canal subgrade and by using closed conduits. By such means as these, seepage can be reduced by an estimated 1.5 million acre-feet by 1980.

9. Satisfactory low-cost type linings, lining procedures, and low-cost closed conduits have been developed and the use of these has made it possible to reduce seepage.

10. Justification for lining is a complicated procedure and in the past it has been determined on an economic basis rather than on the basis of conservation of natural resources.

11. Important data are being accumulated on the cost of maintenance and on the service life of accepted and experimental new linings.

12. Feasibility of large-scale applications of monolayers for reservoir evaporation reduction has been indicated, but economical uses are still dependent on a continued research program embracing the study of basic physical and chemical properties of monolayer forming materials. By treating reservoirs with monolayers, an estimated 2 million acre-feet of water could be saved annually by 1980 in the Western United States.

13. It is known that the efficiency of such applications can now be considerably improved and that the cost of such treatments can be substantially reduced.

14. On the basis of present-day material and labor costs and upon projected improvements in techniques and efficiencies of film-forming materials, it is estimated that by 1980 the costs of water saved could be reduced to about one-fourth of present-day costs of $40 per acre-foot.

15. Overwatering of lands results in the basin loss of water through evaporation and evapotranspiration. Such overwatering has many causes, including: poor water management and measurements, lack of understanding of water needs, effects of existing water laws and water rights, and operating economics.

16. In a number of river basins in the Western United States the only remaining source of additional water is the reduction of consumptive waste and evaporation loss. Consumptive waste can be reduced by about 1 million acre-feet by 1980 through an intensive effort to eradicate nonbeneficial plant growth.

17. There is, at present, no comprehensive program for accurately estimating or evaluating infestations of phreatophytes on the basis of locality, density, type or needed methods of destruction.

18. In some cases water-right law may need clarification regarding ownership to water developed as a result of measures to minimize losses.

Recommendations

It is recommended:

1. That study and research be initiated or continued on methods, procedures, materials, and techniques associated with evaporation reduction through use of monolayers.

2. That research and experimentation be continued to develop practical and inexpensive materials, procedures, and equipment for reducing seepage.

3. That an active program for mapping areas of nonbeneficial plant growth be initiated and that studies and research be expanded in the fields of hydrology and ecology for the purpose of reducing consumptive waste.

4. That the present program of study of weed control be continued and expanded to obtain information on nonbeneficial weeds to determine their water needs and their environmental characteristics; to develop inexpensive chemicals for weed control that are nontoxic to man, beast, and field grown crops; and to develop more efficient equipment for eradication for the purpose of reducing consumptive waste.

5. That a program be initiated for study and research to improve water-measuring devices, water administrative procedures and methods for water application to increase irrigation efficiencies.

6. That an organization be assigned the responsibility of collection, evaluation, and dissemination of data associated with water losses.

7. That consideration be given to clarification of water-right law regarding ownership to water developed as a result of measures to minimize water losses.

Factors Relating to Problems of Water Storage and Transportation Efficiency

WATER STORAGE

Any factor which decreases seepage, evaporation, or consumptive waste in a reservoir will thereby increase the reservoir's storage efficiency.

Seepage

An average reservoir seepage loss is considered to be about 1 percent of the reservoir inflow. Seepage at a damsite is more rigidly controlled than elsewhere in the reservoir to insure the structure's stability. Information available indicates that reservoir seepage ranges from negligible amounts to 5 percent of the reservoir inflow (fig. 2).

Consumptive waste

Reservoir consumptive waste is the total evapotranspiration from the fringe area of the reservoir. Consumptive waste may be severe when delta areas become infested with phreatophytes. Usually the consumptive waste varies from about 1 to 20 percent of reservoir inflow. The average is estimated to be about 2 percent of reservoir inflow (fig. 3).

Evaporation

Reservoir evaporation ranges from less than 1 percent to about 20 percent of reservoir inflow. The average evaporation loss is approximately 5 percent of reservoir inflow.

RIVERS

Seepage

Seepage occurs where river alluvium acts as a carrying medium to transport water from the river to natural or artificial points of discharge. River seepage estimates are sometimes made to determine aquifer recharge capability. These analyses are usually confined to specific studies.

A transportation charge which includes seepage, evaporation, and consumptive waste for moving project water in natural channels is usually made by the State official responsible for administering water rights and usually is some percentage of the quantity of water transported. This procedure is a rule-of-thumb method that has been generally accepted.

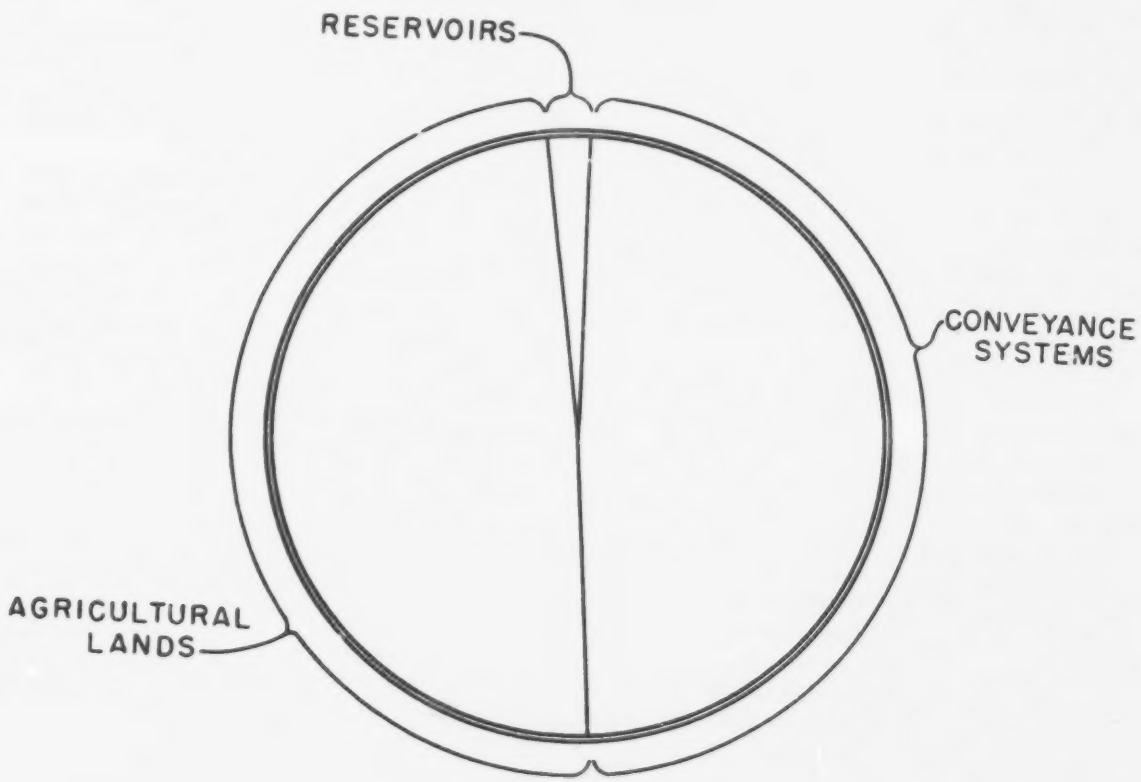

FIGURE 2.—Irrigation project seepage.

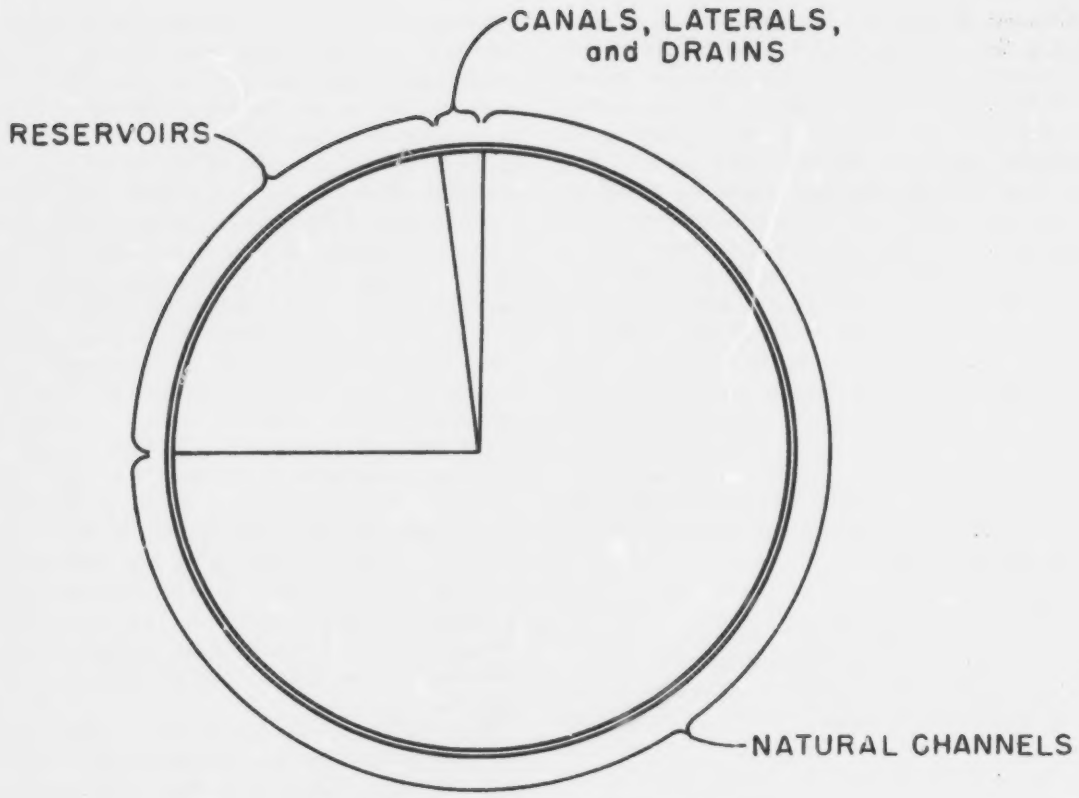

FIGURE 3.—Irrigation project consumptive waste.

Consumptive waste

Under natural conditions the flood plains of some rivers may be covered by vegetative growth. The water consumed by these plants has been estimated to be as much as 25 million acre-feet per year from 16 million acres (mostly flood plains) in the 17 Western States.

The amount of water consumed by vegetative growth is primarily related to plant species, soil quality, ambient temperature, water table depth, precipitation, water quality, geographic location, and volume-density of the vegetative growth. Such an array of variables makes it difficult to develop accurate estimates of consumptive waste. Studies and experiments are underway by several Federal, State, and private agencies to establish more dependable criteria upon which the estimates may be based.

Evaporation

The evaporation from river water surfaces has seldom been estimated in hydrologic studies, and as yet, no practical method has been developed to control or reduce this evaporation. It is not considered an appreciable factor in basin water accounting.

CANALS

Operational waste

Water intentionally turned out of a canal system except to users is called operational waste. This waste water usually leaves the area as surface flow in natural channels.

There are two principal reasons for using water for this purpose:

First, in scheduling water delivery, operation is considerably simplified if the main headworks can be left at a predetermined setting somewhat in excess of need, and turnouts to water users opened or closed as required. Excess water is normally allowed to pass out through wasteways.

Second, the canal system may be at capacity operation when a rainstorm necessitates closing farm deliveries to avoid overwatering crops. All water in transit and all rainwater taken into a canal system that cannot be ponded must be diverted from the system at a wasteway to avoid damage.

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Releases of this kind are generally to streams flowing through the project area and often are not recoverable for use in the particular project for which the water was intended. In some carrier systems it is feasible to provide equalizing or detention reservoirs, but even with these it has not been economically practicable to avoid all operational waste. In any operational waste a small portion of the water will be lost through consumptive waste, but the larger part of it can usually be put to beneficial use in the river basin.

The quantity of water required for operational waste purposes has a tremendous range. In a closed pipe system the amount of waste is negligible. In a well-managed irrigation system, operational waste is about 5 percent of the diversion requirement. Under abundant water supply conditions, one-half of the water diverted may be returned to a natural channel without being used for irrigation.

Seepage

The term "seepage loss," as used in many technical papers and project reports, has a particular meaning that may be quite misleading unless explained. In this broad use it means the difference between all water diverted at the system headworks and the water reported as delivered to the users. The term "seepage loss" thus used will contain all water seeped from the canal, evaporation and evapotranspiration from the transport system, operational waste, and mismeasurements. A review of several systems has shown that actual seepage sometimes constitutes only a minor percentage of the total reported in the term "seepage loss." In the following discussion the above items will be separated.

Seepage from a canal system may be of such importance that the economic life of a project depends on its proper control, or it may be of no practical importance whatsoever. Where seepage does not harmfully reduce project supply it may still create serious problems of bank stability or reduced land productivity through high water table or increased drainage and maintenance costs, and may require control.

In a particular reach of canal the problem of whether to line the canal to stop seepage, recover the seepage water in drains, or to tolerate a waterlogged area is a question of responsibilities, economics, safety, etc.

The amount of water seeping from a canal system will be affected by the character of the material traversed, action of capillarity and gravity, deposition of silt, depth of water in the canal, relative extent of the wetted area, velocity of flow, temperature of soil and water, location of the water table relative to the surface of the water in the canal, ground slope at right angles to the direction of canal flow, percentage of air in the soil, and chemical nature of the soil and water. Some factors are easily determined. There are, no doubt, some unrecognizable factors affecting seepage. Known methods of evaluating the relative importance of a few of the several factors are expensive and time consuming. When data on the many variables are collected, the effects of individual factors are so closely interwoven that it is difficult to evaluate them.

The various combinations of these numerous variables necessitates considering each project or even each reach of canal as a specific problem and also makes generalizations and averages misleading unless their applicability is clearly understood.

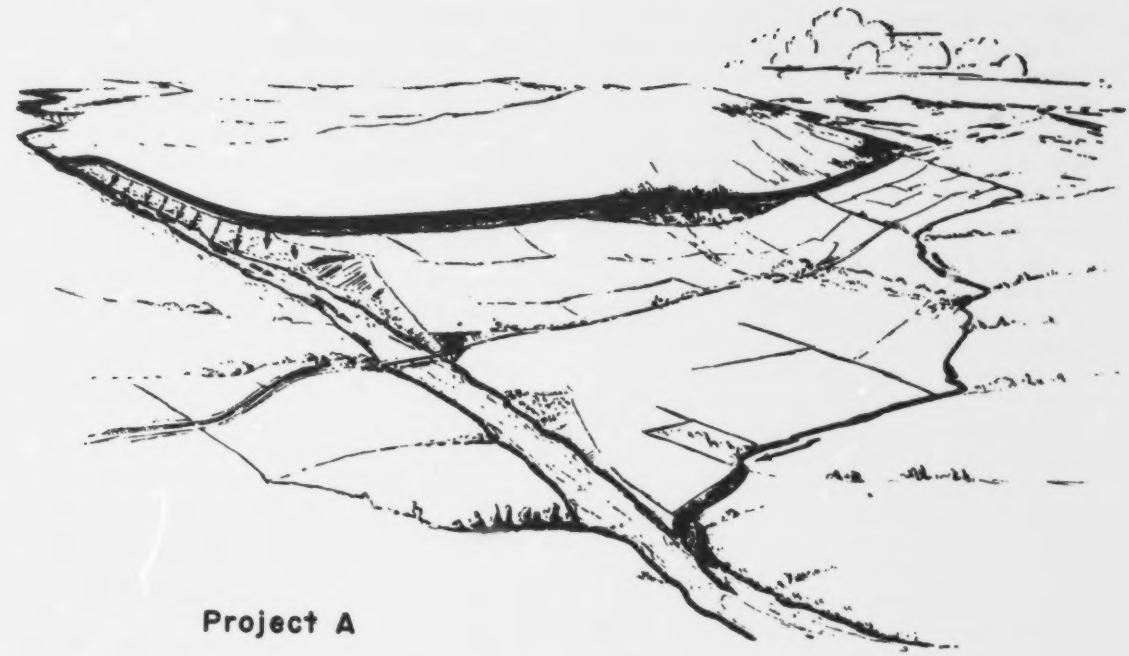
To illustrate the effect of these variables on the question of water conservation two similar projects, composed of features from several projects, are discussed as hypothetical projects A and B (fig. 4).

Project A has access to a plentiful water supply in upstream storage, but project B has a limited water supply. Downstream from project A there are other users from the river while below project B there are none.

Project A

From the point of river diversion the canal is located along the river, then follows a hillside above the project lands to a wasteway at a natural channel which returns operational waste to the river. The reach of canal paralleling the river has a high seepage rate downward into a gravel layer that forms the river channel. Where the canal leaves the river and follows the steep hillside, the soils are moderately impermeable, and the seepage rate is low.

The canal reach paralleling the river is stable yet shows a high seepage rate; however, the seeped water returns immediately to the river and becomes available for downstream use. Along the steep hillside reach, even though the seepage rate is low, the canal section becomes wet and may cause disastrous slides. There would, in this instance, be little justification for lining the section of the canal along the reach where there was a high seepage, but the more impervious hillside sec-



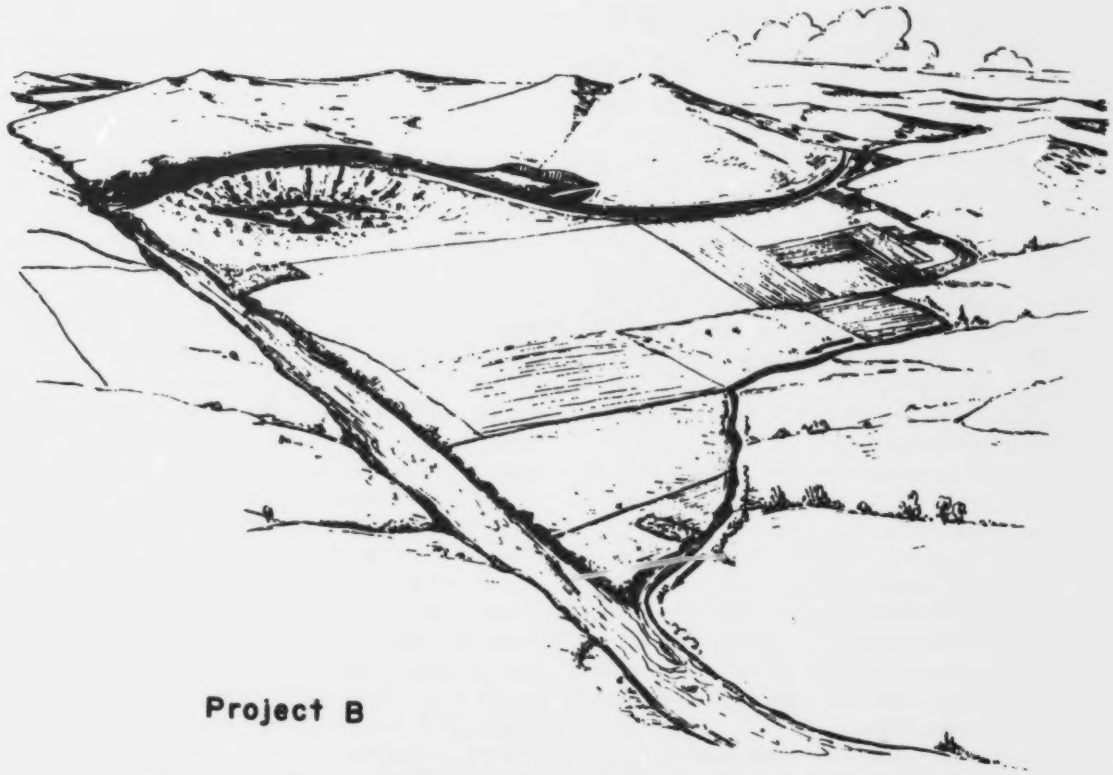


FIGURE 4.—Hypothetical projects.

tion probably would require lining for stability and safety to lands lying below the canal. The difference between river diversion measurements and the sum of user turnout measurements for project A might show a seepage loss of 50 percent as presently reported, yet there would be very little basin loss of water.

Project B

This project has a main canal which swings away from the river through moderately tight soils overlying a clay layer which outcrops in grazing lands between the canal and river. In the project area the canal is in mildly expansive clay, a soil which is usually almost impermeable, and then terminates in a natural channel back to the river.

Because of physical factors the seepage rate in the canal between the river diversion and the project lands is relatively low. However, even small amounts of water seeping from the canal would follow an underlying clay layer and waterlog adjacent grazing lands. Since drainage of these grazing lands probably would be expensive and since there is no downstream basin or project use, lining the canal probably would be justified.

In the expansive clay reach, lining to control seepage would not be required; however, a stabilization lining such as gravel might be needed to avoid maintenance problems due to erosion of the canal banks.

Water diverted into the natural channel as operational waste to simplify project operation would be lost to the project, so to conserve the limited water supply a regulating reservoir beside the canal probably would be justified to simplify operation and to decrease operational waste.

Project B probably would report a seepage loss of 10 percent or less.

Comparison of projects A and B.—Project A reporting 50 percent seepage loss may have less basin—or actual—loss than project B reporting 10 percent seepage loss. To require project A to line the seeping reach of canal along the river would accomplish little from a basin standpoint. If project A were required to provide an operational reservoir to reduce operational waste, evaporation loss would be increased and hence actual basin losses increased.

A project-by-project and canal reach-by-canal reach investigation is considered necessary to make a determination of justifiable expenditures.

Water measurement

Irrigation water is measured for a number of reasons, with different required accuracy being economically justifiable in each instance. Two major points, or types, of measurement have significant bearing on project development and water use.

Headworks measurement is made wherever the project receives its water supply as a separate quantity of water. The device used for measurement and the record kept are usually governed by State laws, interproject agreements, or other such controls. These measurements are usually quite accurate and the total quantity of water diverted in a year is adequately controlled.

Individual user measurements vary widely between projects. Farm turnout measurements may have meters of certified accuracy which include a totalizing device to record the quantity of water delivered (usually in acre-feet). The measurement may be accurate for rate of flow, with quantity delivered computed from time of flow, or the turnout may be simply a gate control to divide water between users with little attention given to the quantity actually delivered.

The types of measuring devices and procedures show that the headworks measurement is probably quite accurate but that turnout measurements may or may not be accurate either for rate of flow or for quantity delivered. The farm turnout may not need a high degree of accuracy to assure an equitable division of available water among users. If this is the case, the accuracy of measurements may not be adequate to evaluate seepage, especially if operational waste is unmeasured.

For the measurement of seepage a recent development is the use of electrical well-logging equipment to detect saturated subgrade soils and indirectly possible seeping areas. This method, with supplemental electrical equipment which may also be further developed to define water movement in the soil, is being investigated as a part of seepage measurements by the Lower Cost Canal Lining Committee. Regardless of method, the results must be sufficiently accurate to define the quantity of water seeped between points on the canal.

Few accurate measurements of seepage, evaporation, and transpiration were made on reclamation projects prior to the lower cost canal lining program in 1946. Lining studies require that seepage rates be determined to evaluate the effec-

tiveness of linings being placed. Such tests were made by carefully controlled ponding, inflow-outflow measurements, or by specially developed seepage meters. Present data on seepage tests cannot be considered as representative of canals and laterals throughout the 17 reclamation States. A major enlargement of the test program is needed.

To establish the value of lining and determine its necessity, reliable data are needed on seepage rates. These data are being gathered but additional emphasis is needed in this field. Accurate measurements at different points in a project and a river basin are required to determine actual basin losses.

Consumptive waste

Consumptive waste from canals is the quantity of water used by phreatophytes and hydrophytes adjacent to and in the canals. In canal systems which have adequate operation and maintenance, the consumptive waste and evapo-transpiration is small. Canals that are choked with hydrophytes or have a heavy infestation of phreatophytes adjacent to the canal may have a significant quantity of water consumed by these plants. Plants, trees, and other growing vegetation along the banks of canals and laterals are the principal contributors to losses of this type. A reduction in these losses can be accomplished by good maintenance of the canal or lateral and its adjacent right-of-way by removal of the nonbeneficial vegetation. Grasses can be substituted for other vegetation where ground cover is required to reduce erosion and stabilize banks.

Evaporation

The range of evaporation from a canal is considered to be a small part of the water carried and rarely exceeds 2 percent of the water diverted and more often is less than 1 percent. In any particular system the loss is generally less than the accuracy of water measurements presently made so the amount must be computed from data on local evaporation rates. One authority has stated that the loss of water due to evaporation from canals and laterals represents less than one-fourth of 1 percent of the flow on an average.

Methods for Increasing Water Storage and Transportation Efficiency

WATER STORAGE

Project storage should provide that combination of reservoirs that will most economically and efficiently regulate the water supply to meet project demands. Consideration should be given to locating reservoirs where they would be subjected to less evaporation and less consumptive waste per unit area. Reservoirs which are deep and have small water surface areas per unit of capacity have less evaporation than shallow reservoirs of the same capacity but with large surface areas.

Operation of reservoirs for minimum evaporation and consumptive waste can be accomplished by having storage held in reservoirs with minimum evaporation and consumptive waste until the water is required.

Evaporation

For more than a quarter of a century it has been known that certain chemical compounds, when applied to water surfaces, are capable of reducing the amount of water lost through evaporation. Until early in the 1950's, however, this knowledge remained more or less a laboratory curiosity. In more recent years the increasing demand on available water supplies all over the world has focused attention on the possible use of chemical applications to help conserve this essential resource.

The chemicals that have been studied for such use are those which form layers 1 molecule thick, called monomolecular films or monolayers, on a water surface and which also have the unique ability to reduce evaporation of the water. Among the materials that can form evaporation reducing layers are the normal long-chain alcohols such as hexadecanol, which are insoluble in water—waxlike solids or liquids.

In 1952, the Bureau of Reclamation began to consider the feasibility of applying monolayers to large reservoirs for water conservation; and, in 1955, a laboratory and field study of this problem was undertaken. In 1958, together with several other organizations the Bureau conducted the first large-scale field tests at 2,500-acre Lake Hefner near Oklahoma City.

The help of such Federal organizations as the U.S. Public Health Service, the U.S. Geological Survey, the Bureau of Sport Fisheries and Wildlife, the U.S. Weather Bureau, and the U.S. Air Force was enlisted in the Lake Hefner studies and associated preliminary investigations. A major contributor to the program was the city of Oklahoma City. Also contributing were several State and municipal organizations and schools, among which are Colorado State Game and Fish Department, Denver Board of Water Commissioners, Northern Colorado Water Conservancy District,

Oklahoma State Department of Health, North Texas State College and Colorado State University.

Valuable work in this field is also being done by many other individuals and organizations, such as Prof. Frank Crow of Oklahoma State University, the Illinois State Water Department, and the Southwest Research Institute. Prof. V. K. LaMer of Columbia University has made valuable recent contributions in fundamental work associated with surface films and monolayers.

Most early work consisted of screening materials and devising efficient and low-cost methods of application. Work done by the Bureau of Reclamation and its collaborators also included investigations to reveal any possible toxic effects of such treatments to lake biota, including game birds and fish, and any effects on water quality, including taste, color, and odor.

Rather extensive investigations into the effects of hexadecanol on various micro-organisms, insects, game fish, and plants commonly found in lakes and reservoirs revealed that no adverse effects on the lake biota resulted from such treatments. Also, observation of the effects of hexadecanol on water quality indicated no adverse results. There was, however, an increase in the density of some of the micro-organism populations, indicating that they were feeding on the alcohol and thus were contributing to attrition losses of the monolayer.

Wind effect is probably the most important single factor contributing to attrition of the monolayer. The monolayer can be compressed by wind action into a solid and washed up on shore. High winds also cause mixing with the water and loss of the monolayer as an evaporation retardant.

The 1958 Lake Hefner tests were conducted for a period of 86 days. High wind conditions or rainy weather prevented treatment on 31 of the 86 days, and generally adverse conditions during the entire period allowed only partial coverage. Even under these unfavorable conditions, the saving in evaporation for the entire 86 days was found by the U.S. Geological Survey to be 9 percent, with savings as high as 14 percent for 1-week periods being measured.

An economic evaluation of the Lake Hefner tests showed that the total cost of the treatments was about equal to the value of the water saved.

Screening tests conducted simultaneously with and subsequent to the Lake Hefner tests indicate that there are presently available several low-cost commercial compounds which are at least as efficient as the hexadecanol used at Lake Hefner. Tests indicate that the efficiency of the monolayers is a function of temperature and that one material may be more desirable than another only through certain temperature ranges.

Several researchers, mainly in foreign countries, have used various solvents to put the long-chain alcohols into fluid form for easier dispensing. This technique has not been used by the Bureau for several reasons. Such cheap solvents as fuel oil, are undesirable for use on municipal water supplies and on reservoirs that are used for recreation facilities. Acceptable solvents are generally too costly to be considered for use in large quantities.

From knowledge gained in the Lake Hefner and associated tests, the effects of hydrologic and climatological conditions on such a treatment have been partially determined. With this information it is possible to estimate roughly, by use of certain simplifying assumptions, the amount of savings and cost of treatment for other reservoirs and under other climatic conditions. For example, it has been assumed that the water surface temperature, the evaporation reducing efficiency of the monolayer, and the extent of film coverage on the various reservoirs are constant for the entire test period. Although these values vary considerably over short periods of time, it is possible to estimate mean values which will give reliable figures for longer test periods. As additional tests are made, it is expected that these estimates will become more refined and more accurate.

Estimates of the potential water savings and costs of saving the water have been made for each of the major river basins in the Western United States, based on reservoirs ranging from 500 to 50,000 acres in surface area. The river basins are as delineated on the 1959 water resources map prepared for the Senate Select Committee on Water Resources by the Geological Survey. These estimates have been made for treatments based on presently available materials and techniques and also on projected conditions for a 1980 treatment. The computations are for evaporation seasons of 4 to 6 months, depending on geographic location of the basin, during which time about two-thirds of the total annual evaporation occurs. Results of these estimates are represented graphically in figure 5.

Results of these estimates indicate that water savings could now be accomplished at an average cost of around $40 per acre-foot in the semiarid Western United States. This is about two-thirds

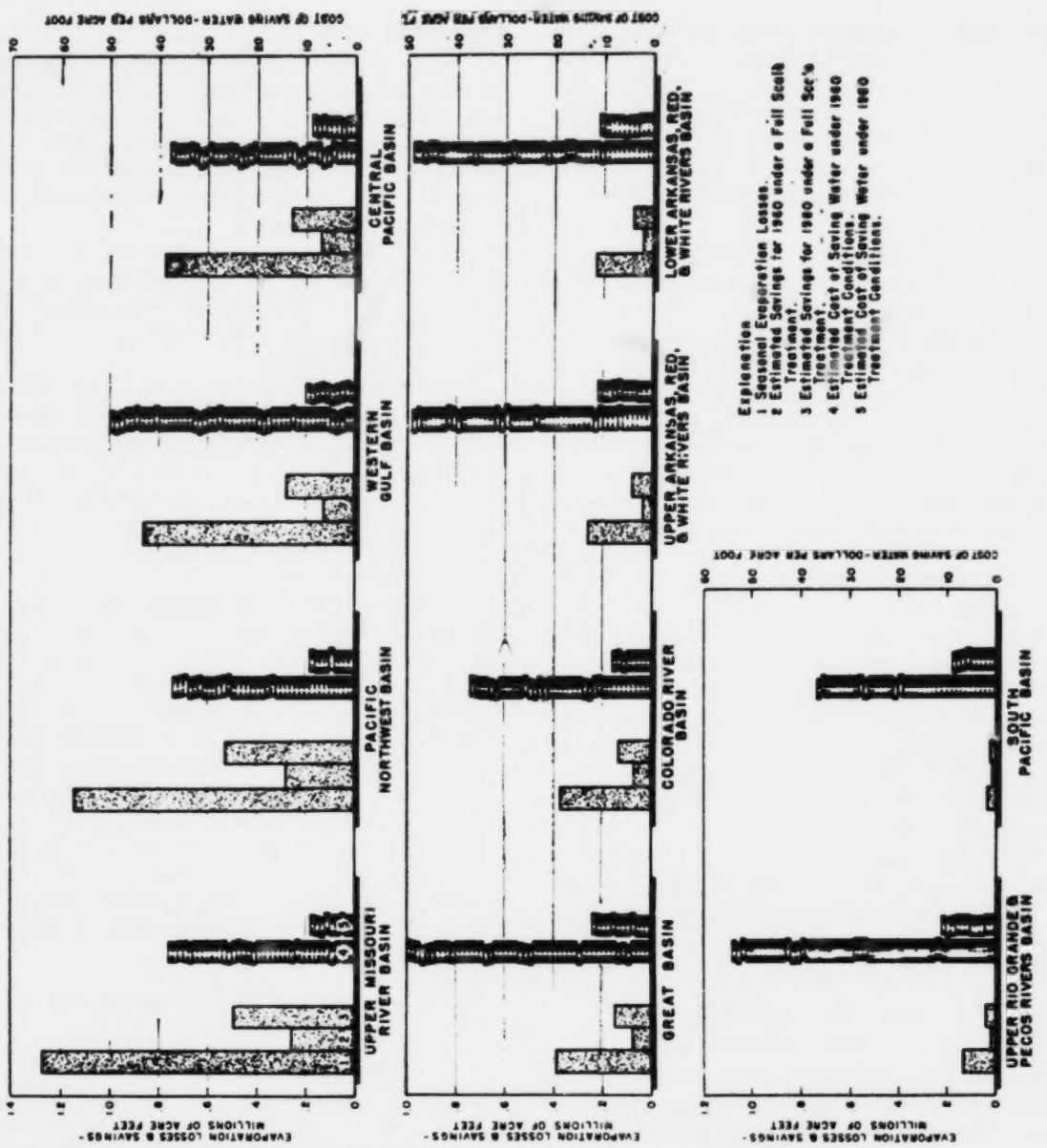

CENTRAL PACIFIC BASIN
WESTERN GULF BASIN
PACIFIC NORTHWEST BASIN
UPPER MISSOURI RIVER BASIN
LOWER ARKANSAS, RED, & WHITE RIVERS BASIN
UPPER ARKANSAS, RED, & WHITE RIVERS BASIN
COLORADO RIVER BASIN
GREAT BASIN
SOUTH PACIFIC BASIN
UPPER RIO GRANDE & PECOS RIVERS BASIN
Explanation
1 Seasonal Evaporation Losses.
2 Estimated Savings for 1960 under a Full Scale Treatment.
3 Estimated Savings for 1980 under a Full Scale Treatment.
4 Estimated Cost of Saving Water under 1960 Treatment Conditions.
5 Estimated Cost of Saving Water under 1980 Treatment Conditions.

FIGURE 5.—Seasonal evaporation losses and estimates of savings and costs of saving water for 1960 and 1980 treatment conditions.

(Reservoirs ranging from 500 to 50,000 acres surface area only)

the cost of treatments made at Lake Hefner, and is computed on the basis of improved techniques resulting from the Lake Hefner experience, but assuming that the same material would now be used. Within the next 20 years, it can be expected that this cost will be further reduced to around $10 per acre-foot. Concentrated efforts in research and engineering on this problem could be expected to bring about this lower cost in savings within a much shorter time than the 20 years indicated.

Another important possible use, not previously mentioned herein, is the reduction of evaporation from stock ponds and small reservoirs. Such ponds are critical to the economies of many western communities where, for example, full utilization of grazing lands is dependent upon the

availability of adequate water for stock. Frequently the evaporation losses from stock ponds are 10 times the consumption. In such a case, a 10-percent reduction in evaporation would double the amount of water available to stock, and it is reasonable to assume that this supply could be increased even more through further research.

Seepage

Seepage at damsites is controlled by a nearly impervious dam and foundation treatment which insures the structures' stability. Seepage from reservoirs can be controlled by blanket linings of clay, concrete, or other material. Small reservoirs are frequently entirely lined with clay, plastic, concrete, asphalt membranes, or other impervious materials, particularly those for industrial supplies where the leakage from the reservoir cannot be recaptured and immediately put into the transportation system, and where the water lost by seepage might result in drainage problems and damages to other usages of the land and water.

Geologic examination of all reservoir sites prior to the construction of a dam is essential to determine the extent of reservoir leakage and if the water might be lost to another basin. Should the geologic examination disclose that seepage cannot be controlled within tolerable limits the site should normally not be considered for development.

Consumptive waste

Evapotranspiration or consumptive waste from reservoirs can be minimized by eradicating hydrophytes and phreatophytes adjacent to and within the reservoir using chemical and mechanical methods for destroying the plants.

CONVEYANCE SYSTEMS

NATURAL CHANNELS

The conveyance efficiency of a natural channel is partially dependent upon the regimen of streamflow. Flows during periods of minimum consumptive waste, i.e., winter rather than summer, that saturate the minimum river section or that saturate the river section for minimum periods all tend to increase the conveyance efficiency of natural channels.

Seepage

Seepage from river channels can be decreased by reducing the channel's wetted perimeter, increasing the water velocity, and by lowering the river water surface elevation with respect to adjacent ground water. River channels may also be lined similarly to canals.

Consumptive waste

Reducing the area of phreatophytes is the most effective means for reducing consumptive waste from natural channels. Eradication by mechanical or chemical means is effective, however, it is usually a never-ending task to keep the areas cleared. This problem can be minimized by changing vegetative cover.

Lowering the water table in areas infested with phreatophytes is another means of reducing consumptive waste. This can be accomplished by river channelization, land drainage, and by ground-water pumping.

In the middle Rio Grande Valley, where about 100 miles of river upstream from Elephant Butte Dam has been channelized, it has been estimated that the water saved in 6 years is worth many times the construction cost. A conveyance channel must be constructed deep enough so the water surface is always several feet below the elevation of the flood plain elevation.

New methods of clearing, disking, and spraying, and new herbicidal sprays are being developed to kill nonbeneficial plant growth. On the middle Rio Grande project a sprayer capable of covering a strip 80 feet wide with one pass is in use. The work done to date has been on a relatively small scale, and before major water savings can be made and large areas converted to beneficial plant use, better methods must be developed.

The following tabulation summarizes the accomplishments in water savings through reduction in consumptive waste by water resource regions. This saving is estimated to be about 1 million acre-feet annually by 1980.

Water salvage by elimination of consumptive waste by phreatophytes

[Thousands of acre-feet]

Basin	Annual water salvage	
	Year 1960	Year 1980
Pacific Northwest		
Central Pacific		
South Pacific		200
Great Basin		100
Colorado Basin	60	400
Upper Rio Grande and Pecos	40	300
Western gulf		
Upper Arkansas-Red River		
Lower Arkansas-Red and White Rivers		
Upper Missouri River		
Total	100	1,000

Evaporation

Minimizing the evaporation losses from river channels can be accomplished by reducing the river water surface area subject to evaporation.

In the search for methods to minimize the losses from existing reservoirs and conduits, one important natural resource has been utilized to a very limited degree. This is the use of ground-water basins to store and transport water. Some ground-water storage basins have huge capacities, and would provide a uniform annual draft.

CANALS

Wastes due to operation and irrigation practices, such as overflooding fields, and failure to keep ditches and structures free-flowing and in good repair, are largely preventable. A good program of education in irrigation practices will decrease these wastes. Reservoirs or even checked canals that pond waste water for later use and drainage systems that deliver water to other users reduce project operational waste.

Seepage can be satisfactorily reduced by installation of relatively impervious linings, or by the construction of closed conduits. Since 1946 more than 42 million square yards of linings of various materials have been placed in approximately 1,700 miles of canals and laterals on reclamation projects throughout the West. These figures do not include many miles of linings and pipelines placed by water users as a part of their normal project operation, maintenance, and rehabilitation.

The cost of generally accepted means of reducing seepage from canals and laterals 10 years ago was prohibitive on many projects, and has increased considerably, along with all construction work. The lower cost canal lining program includes laboratory and office research, surveys of existing installations, seepage determinations, field experiments, and development of equipment aimed at reducing the cost of seepage control. The assistance of other Federal agencies, colleges, universities, and industry has been solicited and through cooperative effort less costly linings of many materials have been developed. The more commonly used field-tested linings are listed in figure 6, with the cost per square yard for placement.

The permeability of some typical installed linings of various types is shown in figure 7. Reliable data prior to lining are also given for comparative purposes. Some of the comparisons reflect a continuing program of evaluation of the linings, including their permeability. The prefabricated asphaltic linings with organic fiber reinforcement and bentonite sediment linings developed to date either appear to be deteriorating with age, or were not sufficiently effective at the time of placement. Plastics, as experimental buried membrane linings, appear to be as effective as other buried membranes based on over 5 years of use.

FIGURE 6.—*Canal lining costs*

	Costs per square yard [1]	
	1947–52	1953–58
Hard surface linings:		
Asphaltic concrete (hot, plant-mixed):		
2 inches thick	$2.20	$2.30
4 inches thick	(2)	[3] 4.90
Asphaltic mortar, pneumatically applied, 1½ to 2 inches thick	(2)	3.70
Asphalt surface membrane, prefabricated, ⅛-inch thick	(2)	[3] 2.50
Portland cement concrete:		
3 to 4 inches thick:		
Unreinforced	2.00	3.90
Reinforced	2.70	(2)
2 to 3 inches thick: Unreinforced	2.70	2.20
Pneumatically applied portland cement mortar, 1 to 2 inches thick:		
Unreinforced	2.20	2.60
Reinforced	2.80	3.50
Soil cement:		
Plastic type, 3½ to 4 inches thick	[3] 1.10	(2)
Standard type, 3 inches thick	(2)	[3] 4.00
Buried membrane linings:		
Hot-applied asphalt with earth and/or gravel cover	1.00	1.10
Prefabricated asphaltic materials with earth and/or gravel cover	[4] 2.00	[4] 1.10
Bentonite	[3] 1.00	1.10
Plastic	(2)	[3] 1.15
Earth linings:		
Thick compacted earth (12 inches or more in thickness)	.60	1.10
Thin compacted earth (less than 12 inches in thickness)	.30	.50

[1] For placement.
[2] No representative cost data available.
[3] Cost represents construction by project forces.
[4] Cost is for small experimental installation.

Experimental studies and tests in using electrical resistivity as a method to detect points of maximum seepage in a canal are underway. Tests made to date are encouraging. Experimental work is in progress on the use of waterborne sealants, natural and chemical, to reduce seepage. A sealant that is effective must also be inexpensive if it is to have practical application.

Pipe is a very effective carrier for water, where water loss and contamination must be held to a minimum. It also reduces consumptive waste and minimizes operational problems. An increase in the use of pipe has resulted from the development of unreinforced cast-in-place monolithic concrete pipe in sizes of 24 to 48 inches. Use of extremely large pipe is feasible for domestic supply but its use will be economically restricted if justification for its use and its cost must be borne by an individual irrigation project. From a water conservation standpoint, all beneficiaries should contribute to its cost and justify its use.

The use of water by nonbeneficial plants along canal banks can be decreased by good maintenance. Facilities for mowing and spraying are available to keep detrimental plant growth along canals under control. Canal structures can and are being designed and constructed so as not to interfere with mowing and spraying operations.

FIGURE 7.—*Permeability of some typical linings*

Type of lining	Date	Field permeability cf/sf/day [1]		Remarks
		Before lining	After lining	
Buried asphalt membrane (hot applied).	1949	[2] 1.31	[2] 0.16	Earth cover.
Buried asphalt membrane (prefabricated).	1950	[2] .84	[2] .06	⅛-inch thick, organic fiber reinforced, earth cover.
	1951	2.30	-------	
	1952	-------	.03	⅛-inch thick, organic fiber reinforced, macadam cover.
	1953	-------	.14	
	1954	-------	.19	
	1955	-------	.39	
	1952	2.73	.02	3/32-inch thick, asbestos fiber reinforced, earth cover.
	1953	-------	.02	
	1954	-------	.02	
	1956	-------	.05	
	1951	2.30	-------	3/32-inch thick, asbestos fiber reinforced, earth cover.
	1952	-------	.05	
	1953	-------	.04	
	1954	-------	.04	
	1955	-------	.13	
	1951	2.30	-------	1/16-inch, glass fiber reinforced, earth cover.
	1952	-------	.08	
	1953	-------	.10	
	1954	-------	.29	
	1955	-------	.34	
	1951	3.05	.27	1/16-inch, glass fiber reinforced, macadam cover.
	1952	-------	.23	
	1953	-------	.07	
	1954	-------	.09	
	1955	-------	.14	
Exposed asphaltic membrane (prefabricated).	1952	2.73	-------	⅛-inch asphaltic sheets.
	1953	-------	.05	
	1953	-------	.18	
	1954	-------	.01	
	1956	-------	.01	
	1952	2.73	-------	¼-inch asphaltic sheets.
	1953	-------	.48	
	1953	-------	.05	
	1954	-------	.05	
	1956	-------	.11	
Portland cement concrete (unreinforced).	1950	-------	[2] .07	3½ inches thick.
	1949	-------	.83	Seepage measured by inflow-outflow methods.
	1949	-------	.50	Do.
	1949	-------	.26	Do.
Pneumatically applied portland cement mortar.	1950	-------	.03	1½ inches thick.
Compacted earth lining..	1950	-------	.07	2 to 3 inches thick.
	1950	-------	.06	Do.
	1949	.40	.13	
	1949	-------	.07	
	1951	.43	-------	Tractor compacted.
	1952	-------	.05	
	1951	1.96	-------	
	1952	-------	.54	
	1953	-------	.66	
	1954	-------	.85	
	1955	-------	1.27	
Soil cement.....	1950	-------	[2] .03	
	1948	[2] .95	-------	
	1948	-------	[2] .03	15.5 percent cement, 3 inches thick.
	1949	-------	[2] .14	Do.
	1948	-------	[2] .14	11 percent cement, 3 inches thick.
	1949	-------	[2] .20	Do.
	1948	-------	[2] .07	17.5 percent cement, 3 inches thick.
	1949	-------	[2] .11	Do.
Sediment sealing (natural sediments).	1952	2.73	.76	
Sediment sealing (bentonite).	1955	[2] 1.04	-------	
	1956	-------	[2] 1.06	
	1955	1.08	-------	
	1956	-------	[2] .75	
	1955	[2] .40	-------	
	1956	-------	[2] .54	
	1955	[2] .40	-------	
	1956	-------	[2] .63	

[1] Permeability rate is given in cubic feet per square foot per 24 hours, often abbreviated as shown or as cfd (cubic feet per day).
[2] Seepage.

WATER RIGHTS

The development of water-right law in the western United States is directly related to mining and irrigation. Practically all of these laws are based upon the appropriative doctrine. Although different local conditions have resulted in many variations, basic principles are essentially the same and have been instrumental in stimulating orderly water resources development.

Existing water-right law requires the beneficial use of water. Likewise, existing water-right law does not, in general, hinder proposed measures for minimizing water storage and transportation losses. In fact, as competition for available water increases more rigorous administration of water rights within the framework of existing law probably will lead to more efficient use of water.

In view of the complex interrelation between surface water and ground-water supplies it is difficult to identify relative water entitlement. In most States clarification of water-right law relating to ground water would encourage more efficient use of overall basin water supplies.

In some cases water-right law may not be entirely clear in regard to specific problems which might arise in connection with the identification of and establishment of ownership to water developed as a result of measures to minimize water storage and transportation losses.

ECONOMIC CONSIDERATIONS

In the 17 Western States, water which was immediately available and could be put to use inexpensively at particular points of use has already been appropriated. Any increase in use can only be obtained at a cost for increasing the supply, improving the quality, or purchasing the rights of other users. A basic question, therefore, is whether the cost will be balanced by the benefit or value of the water thus obtained. The problem is not entirely one of value, for water users are accustomed to paying water charges which are substantially less than the economic value of water. With this attitude of viewing water as a low-cost commodity, effective action will depend upon determination of what potential purchasers are willing to pay. Thus, the vendibility of salvage water will strongly influence the probable salvage activities. These activities will be practical in those places and for those purposes which are willing and able to bear the salvage cost under the circumstances prevailing at that time. Where the need and demand for water is high, such activities are more likely to occur. The price paid for water may be expected to rise as economic competition for available water increases and as more expensive competitive sources of supply are developed. Also, in areas of declining water tables,

increasing costs of pumping may become greater than the alternate cost of saving water.

The price being paid for irrigation water in the Western States today is a composite of payments to cover the cost of constructing irrigation works and payments to meet annual expenses of operation, maintenance, and replacement. These prices are very low, in part because the irrigation facilities may have been constructed under lower price levels of the past, in some cases because only a partial rather than a total water supply is being delivered, and partly because of the prevailing concept that irrigation water should be made available at low rates.

Prevailing prices for irrigation water in most parts of the West are less than $10 per acre except for specialty crop areas. Present prices per acre-foot of water are under $10 except for the South Pacific Basin where in some instances they exceed $35. These values are admittedly low, as irrigation benefits per acre range from $10 to $50 in most parts of the West, and range from $40 to $100 in the Northwest and California.

The value of water for power depends upon the availability of powerplant sites with sufficient head for the water to produce appreciable value. At present plants, values ranging from less than $1 to about $12 per acre-foot are possible by the use of salvaged water at one or more existing installations.

Present prices for municipal water are noticeably higher than those for power or for irrigation. They generally range from $10 to $25 per acre-foot, and range from $35 to in excess of $75 per acre-foot in the South Pacific Basin.

Decisions concerning the location of water use, of course, cannot be made entirely on the basis of prices. The present price may be expected to increase substantially, and perhaps double, as the growth of western cities and general economic development proceed between now and the year 1980. However, water rights and the legal framework of treaties and compacts will require that the development of additional water supplies seek maximum economic values only within legally determined subareas.

Figure 8 presents by water resources regions information on prevailing prices and benefits of water used for irrigation, power production, and municipal and industrial uses in these regions. The data presents ranges of cost and values by water resources region. The value of water for power represents hydroelectric development to date. As the Columbia, Colorado, and Missouri Rivers increase their hydroelectric development, the value of water for power will increase.

Fields for Continued and Future Study and Research

Continued effort should be directed in the following general areas of research for reduction in evaporation, consumptive waste, and seepage. These areas are summarized as follows:

1. Evaporation reduction through use of monolayers.
2. Consumptive waste reduction.
3. Seepage reduction.
4. Weed control.
5. Improved irrigation practices.

Each area is discussed briefly in the following paragraphs.

1. Since feasibility of large-scale applications of monolayers for reservoir evaporation reduction has

Figure 8.—*Present benefits and prices of water for irrigation, power, and municipal use, by water resource region*

Water resource region	Irrigation						Power value at present plants	Municipal, present price
	Benefits	Construction repayment	Operation, maintenance, and replacement cost	Total water charge	Gross diversions	Present price		
	Dollars per acre	*Dollars per acre*	*Dollars per acre*	*Dollars per acre*	*Acre-feet per acre*	*Dollars per acre-foot*	*Dollars per acre-foot*	*Dollars per acre-foot*
Upper Missouri Basin:								
Montana, Wyoming	10-40	1- 2	2- 5	3- 7	2 - 6	1 - 3	0.5- 4	10-15
Colorado, North and South Dakota	20-40	1- 2	3- 8	4-10	3 - 5	1 - 3	1 -12	5-10
Kansas and Nebraska	40-50	2- 5	2- 3	4- 8	3 - 5	1 - 3		10
Upper Arkansas-Red Basin	40	1	3	4	1.5 - 3	1 - 2		10-25
Western Gulf Basin	35-50	5	8-10	13-15	2 - 3	4 - 7		15-20
Upper Rio Grande and Pecos Basin	20-50	1- 5	5-14	7-17	4 - 5	1 - 4	.5	20-25
Colorado River Basin	15-35	1- 3	1- 7	2- 8	5 -10	1 - 2	.5- 2	15-20
Specialty-crop areas		2- 7	10-20	12-25	3 - 4	3 - 8		10
Great Basin	10-20	1- 3	1- 3	2- 6	7 - 9	1 - 4		
Salt Lake City area	40-50	3- 6	2- 5	5-11	3 - 4	1 - 4		10-15
Pacific Northwest Basin	20-40	1- 5	3- 6	4- 9	5 - 8	1 - 2	1- 1.5	
Specialty-crop areas	50-70	6-10	9-11	11-19	3 - 5	2 - 6		
Central Pacific Basin	40-70	3- 5	5- 7	10	3 - 5	2.5- 3.5	1- 1.5	15-20
South Pacific Basin	Over 100			35-50	1.5- 2.5	35		25-75

been indicated, advancement of this technique to a point where its use on municipal and irrigation water supplies is economical will depend on a continued research program embracing the study of basic physical and chemical properties of the monolayer forming materials.

A study of the chemical properties of the materials, the manufacturing processes and the source of the raw materials is expected to reveal why certain of these give more efficient monolayers than other seemingly similar materials. It is expected that efficiency-water surface temperature correlations will permit formulation of more efficient monolayer forming compounds for use at certain temperature ranges. A study of the factors contributing to the destruction of the monolayers under field conditions, for example, biologic attrition, should reveal methods for prolonging the life of a monolayer. Use of additives for inhibiting or preventing the rapid consumption of the monolayer forming materials by bacteria in the reservoirs is now under consideration, and a substantial decrease in this factor alone would greatly increase the effective life of a monolayer. Use of additives to increase monolayer spreading rates and resistance to destruction through reaction under ultraviolet or infrared radiations is also expected to add to the useful life of the film. In considering use of additives it will be necessary to make certain that no adverse effects on water quality will result and that the additives will not destroy the evaporating reducing efficiency of the monolayer. These are only a few of the considerations for further research in the basic physics and chemistry of the monomolecular films.

In preparation for future tests to be conducted at various suitable reservoir sites, work should be initiated in the immediate future to collect data on the natural evaporation losses, seepage losses, and such meteorological factors as wind velocities, precipitation, and air and water temperatures. These data will be required for determining the economic feasibility of treating each reservoir and also for evaluating treatment made to the reservoirs.

To summarize, the following laboratory and field tests should be initiated or continued:

(*a*) Study techniques of application such as dusting with powdered materials, spraying molten materials, etc.

(*b*) Collect and correlate meteorological data, such as wind conditions, with monolayer behavior and efficiency.

(*c*) Study use of additives to permit emulsification, suspension, etc., in water for improved application.

(*d*) Test new materials.

(*e*) Temperature-efficiency correlation tests.

(*f*) Study of effects of monolayers on lake biology.

(*g*) Use of bacteriostats and other additives to prolong life of the monolayer and to improve its efficiency.

(*h*) Study of effects of monolayer forming materials on water quality.

(*i*) Effects of monolayers on humans.

(*j*) Chemical, chromatographic, infrared, X-ray, etc., analysis of film-forming materials to secure fundamental knowledge on how they operate.

(*k*) Study of manufacturing processes and raw material sources as associated with efficiency of the monolayer as an evaporation retardant.

(*l*) Study of gas transfer through monolayers, particularly any effect on dissolved oxygen.

Consideration should also be given to further testing the use of monolayers in the following areas:

(*a*) Use on ricefields and cranberry bogs.

(*b*) Use on canals and rivers.

(*c*) Use on steam plant reservoirs.

(*d*) Use on snow.

2. It is generally considered that phreatophytes are responsible for most of the consumptive waste that occurs. In an effort to increase our usable water supplies, consideration should be given to reducing consumptive waste through research and study in the areas of hydrology, ecology, and eradication and control.

Further study and research are needed as follows:

(*a*) To determine the relationship between rate of water use and depth to water table for selected species of phreatophytes in variable climatic and other environmental situations.

(*b*) To determine the relationship of water use to the volume-density of growth for different species of phreatophytes and various climatologic conditions.

(*c*) Changes in water use by phreatophytes that may occur under natural conditions in various areas.

(*d*) To determine methods of propagation, such as seed viability and dissemination, root growth and effect of environmental factors thereon.

(*e*) Evaluate growth and development of seedlings and effect of environmental factors on their growth.

(*f*) Changes of volume-density that would occur under natural conditions.

(*g*) Natural biological parasites.

(*h*) Evaluate all presently available herbicides on selected species of phreatophytes in different climatological situations.

(*i*) Development of new herbicides and new techniques of application.

(*j*) Evaluate present methods of mechanical eradication with a view of developing improved machinery and techniques.

3. Loss of water from storage and conveyance systems of seepage, though it may not be severe from an overall basin concept of loss, is of major importance to the individual project and will, at times, govern the economic stability of the area.

Studies and research need to be continued in the following areas if seepage reduction is to be achieved economically:

(*a*) Improved lining materials.

(*b*) Use of sealants:

(1) Physical types to include sediments.

(2) Chemical types either those that can be waterborne and deposited over the wetted perimeter of a waterway, or those that can be directly applied to the subgrade materials by spraying.

(3) Biologic types.

(*c*) Closed conduit:

(1) Cast-in-place concrete pipe.

(2) Plastics.

(3) Other synthetics or natural materials that can be formed into pipe.

(*d*) Seepage rate detection:

(1) Radioisotopes.

(2) Electrical resistivity.

4. Water consumed by the growth of weeds in and adjacent to storage and conveyance systems is a loss of water that is undesirable and can be eliminated. The areas that need to be examined to develop an effective weed control program include the examination of rates of water use of various weeds, chemical and mechanical measures to control weeds, and the effect of chemicals on humans, plants, and animals. Submersed and emergent aquatic weeds if allowed to grow unchecked can result in stagnating flows in canals. Further research is needed on their control especially in large canals.

5. Significant water savings can result from improved irrigation practices. Research in this field should be directed toward more accurate water-measuring devices, improved water-handling procedures, and demonstration of maximum production with minimum use of water. A real need exists to study and establish economic water requirements for various agricultural crops. Technical procedures developed to establish consumptive use requirements should be reviewed. The need exists for simple soil moisture measuring devices which indicate when irrigation water is required. Studies should be made on ways of improving irrigation practices and procedures to obtain maximum water efficiency to avoid water loss at the farm, factory, or home.

Federal Participation in Evaporation and Seepage Research

The role of Federal agencies in research and development associated with minimizing water losses must be based upon the general concept that water is a natural resource of the entire United States. State and private agencies have a very significant role in these programs. It is visualized that in many instances the Federal Government might act as a central coordinating agency. The States would deal with the problems common to them, and universities and private organizations would deal with specialized, specific, or local problems.

It is acknowledged that water is one of the most precious of our natural resources. We know the quantity is limited. The conservation and wise use must be fitted to the requirements of today and plans made for adjustment to the needs of the future. Any water conservation program jumps into an area in which the United States as well as Canada and Mexico have a joint interest.

In the role of coordinator, the Federal Government should utilize State, educational, and private organizations to the maximum. The Federal Government should not exert undue influence in this field except as a protector of one of the Nation's basic natural resources.

Federal organizations may be best equipped to finance and carry out large-scale field tests. On the other hand, universities, research groups, and specialists may be in a better position to carry out specific research projects associated with solving the many problems that require specially equipped laboratories and experts trained in the various specialized fields of science associated with these studies.

Limited study and research is underway in the field of water conservation. Technical papers reporting upon these efforts are published from

time to time. It appears desirable that responsibility be assigned to some entity that will collate, evaluate, and disseminate all efforts in these fields. The Federal Government might be well suited to undertake this assignment and provide direction in further research programs.

In summary, the Federal Government has an overall responsibility in water economy which is basic to the future development and stability of the Nation as a whole. This responsibility cannot be delegated. Therefore, active and aggressive measures should be initiated to insure that the Nation's water requirements can be supplied.

Methods of financing continuing research on water savings vary considerably within the framework of the several interested agencies of the Federal Government. For example, research activities of the Agricultural Research Service are generally financed by nonreimbursable funds, whereas similar activities of the Bureau of Reclamation are generally financed by reimbursable funds. Because of the wide universal application of the knowledge to be gained from these research activities, it might be advantageous to establish a uniform financing procedure by setting up a continuing nonreimbursable fund for such studies.